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Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Kowalewski, B., Fereczkowski, M., MacDonald, E., Strelcyk, O., & Dau, T. (2016). *Model-based fitting of compression settings using narrowband stimuli*. Poster session presented at International Hearing Aid Conference 2016, Tahoe, CA, United States.

Model-based fitting of compression settings using narrowband stimuli

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Introduction

Most state-of-the-art hearing aids apply multi-channel dynamic-range compression (DRC). Studies using speech intelligibility as an outcome measure have shown mixed results in terms of the benefits of compression over linear amplification (e.g. Davies-Venn *et al.* 2009; Goedegebure *et al.* 2001, 2002; Kates 2010; Olsen *et al.* 20005; Souza *et al.* 1999, 2012; Yund and Buckles 1995a,b).

Compression provides increased audibility of speech components, but at the same time introduces distortion of spectral and temporal envelopes of speech. The two effects may offset each other, depending on what cues the individual hearing-impaired listeners rely on. Therefore, it is difficult to disentangle them when speech recognition is used as an outcome measure.

Edwards (2002) suggested using a set of relatively simple outcome measures, based on narrowband signals, for the evaluation of hearing-aid signal processing.

We present a compression design that has been optimized, within the framework of a computational model, for improving the performance of (aided) hearing impaired listeners in temporal and spectral resolution-related tasks.

Listeners

3 normal-hearing (NH) listeners
5 hearing-impaired (HI) listeners

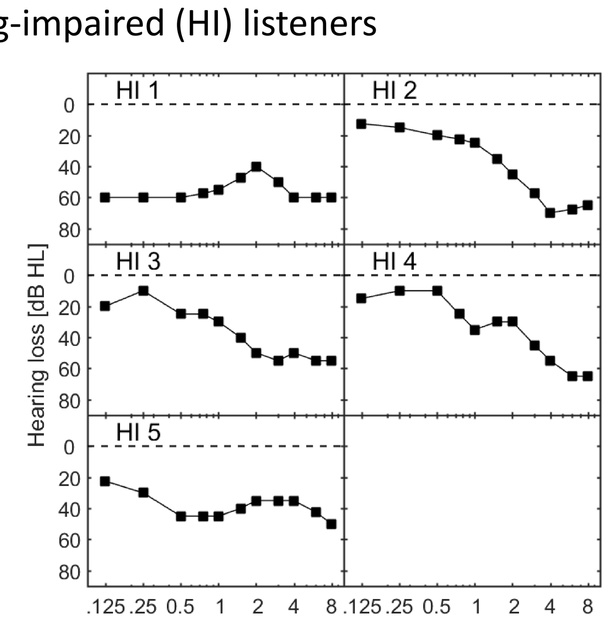


Fig. 1. Pure-tone audiograms of the hearing impaired listeners

References

Davies-Venn E., Souza P., Brennan M., Stecker C. G. 2009 *Ear & Hear.* 30, 494-504; Goedegebure A., Hulshof M., Maas R. J. J., Dreschler W. A., Verschuure H. 2001 *Audiology* 40, 10-25; Goedegebure A., Goedegebure-Hulshof M., Verschuure H, Dreschler W. A. 2002 *Int J Audiol* 41 414-428; Kates J., 2010 *Int J Audiol* 49, 395-409; Olsen H. L., Olofsson Å., Hagerman B., 2005 *Int J Audiol* 44, 421-433; Souza P. E., Bishop R. D. 1999 *Ear & Hear.* 20, 461-470; Souza P. E., Wright R., Bor S. 2012 *J Speech Lang Hear. R.* 55, 474-486; Yund W. E., Buckles K. M. 1995 J Acoust Soc Am 97 (2) 1206-1223; Yund W. E., Buckles K. M. 1995 J Acoust Soc Am 97 (2) 1224-1240

Acknowledgements

This IHCON contribution is supported by the IHCON student scholarship.
The project is supported by Phonak and the Technical University of Denmark.

The first author would like to thank Henrik Gert Hassager and Alan Wiinberg for their valuable comments and help with model fitting.

Experiments

Aided/unaided experiments and simulations in NH and HI:

- Decay of forward masking, wideband noise at 85 dB SPL (unaided)/75 dB SPL (aided), signal at 1 and 4 kHz
- Spectral masking patterns, narrowband 75 dB SPL masker at 1 and 4 kHz

In HI only: temporal masking curves (TMCs) measurement for a behavioral BMIO estimates at 1 and 4 kHz

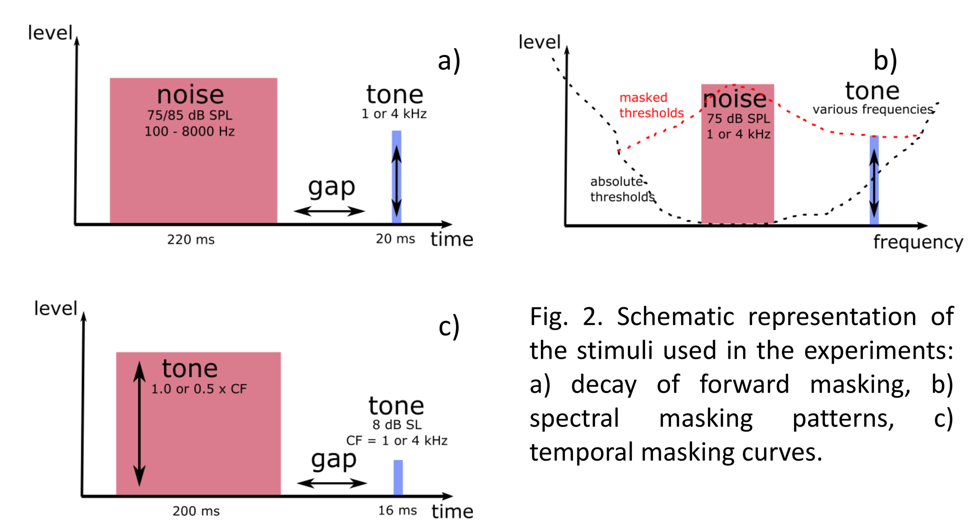


Fig. 2. Schematic representation of the stimuli used in the experiments: a) decay of forward masking, b) spectral masking patterns, c) temporal masking curves.

Hearing-aid processing and auditory perception model

Hearing aid:

- Instantaneous attack, 10 ms release (RC)
- 24 channels, ERB-like
- Frequency- and level-dependent insertion gain based on NAL-NL1

Auditory model:

- CASP model (Jepsen *et al.*, 2008)
- Individualized based on the audiogram and the TMC data (Jepsen and Dau, 2011)

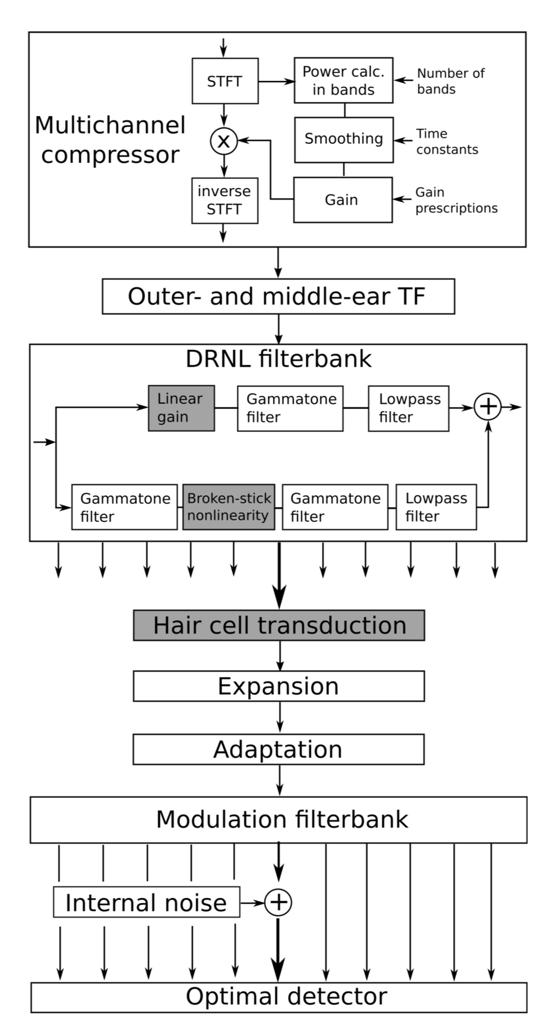


Fig. 3. CASP model structure including the hearing-aid compression preprocessing. Grey-colored blocks represent the model stages subject to changes due to the individual hearing loss.

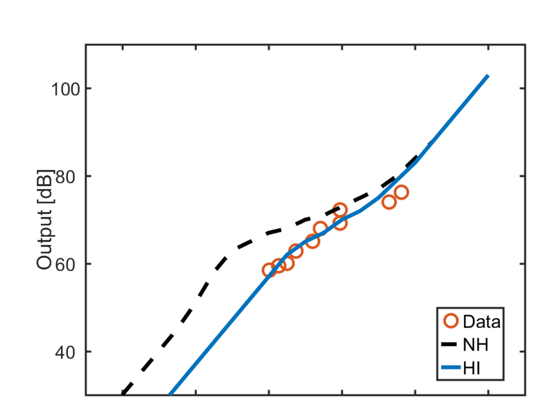
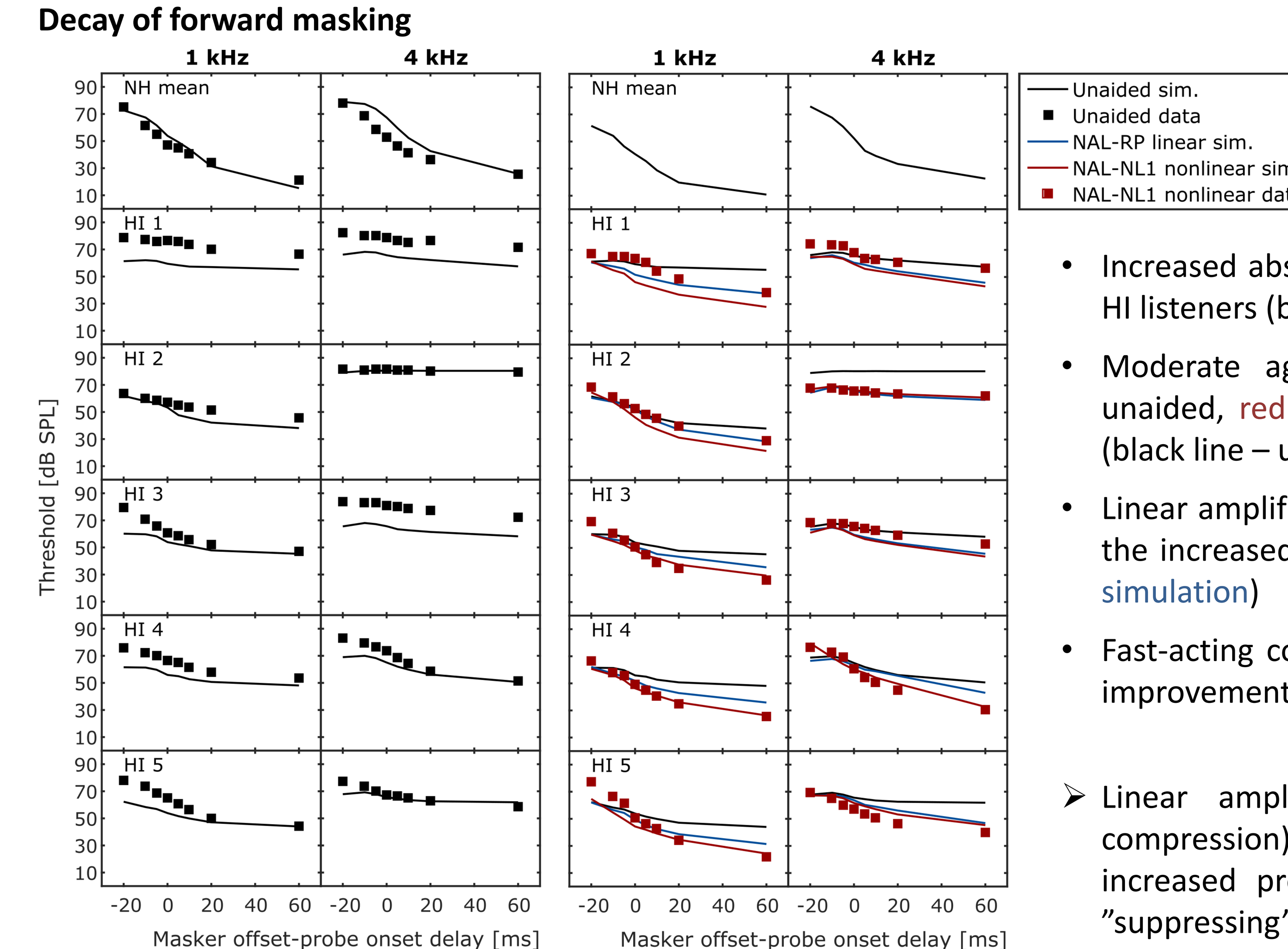


Fig. 4. Fitting of the model to individual data. Based on the TMC, an individual BM I/O estimate is obtained. A set of DRNL parameters is found that produces a best-fitting model input/output function.

Results

Decay of forward masking



- Increased absolute threshold and slower decay in unaided HI listeners (black squares and lines)
- Moderate agreement between data (black squares – unaided, red squares – nonlinear aided) and simulations (black line – unaided, red line – nonlinear aided)
- Linear amplification; Moderate improvement as a result of the increased sensation level (SL) (blue line – linear aided simulation)
- Fast-acting compression (nonlinear amplification); Further improvements at 1 kHz (red line)

➢ Linear amplification (and therefore also slow-acting compression) can improve the decay in HI due to the increased probe SL. Any further improvement requires "suppressing" the masker with subsequent amplification of the probe and is possible with a compressor with a very short release time.

Spectral masking patterns

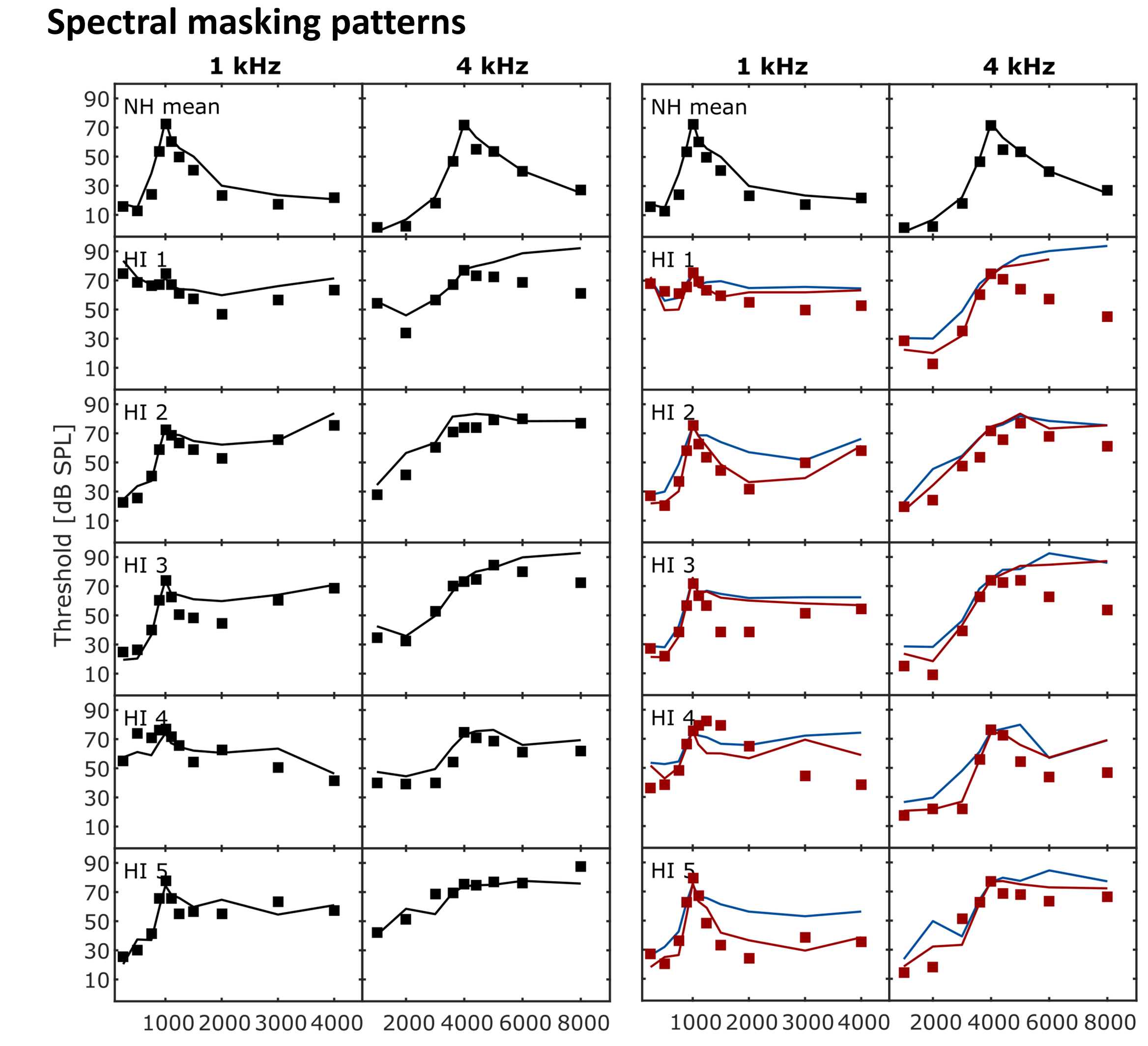


Fig. 5. Experimental results. Top panels: decay of forward masking, bottom panels: spectral masking patterns. Left: unaided data and simulations, right: aided data and simulations.

- Flatter patterns, excessive upward spread of masking (USoM) in HI listeners (black squares and lines)
- Model overestimates masking at high frequencies
- Linear amplification; Improvements mostly at the low-frequency skirt at 4 kHz due to the improved audibility. No reduction in USoM (blue line – linear aided simulation)
- Multi-channel compression; Improvement if the residual frequency selectivity is relatively good. Increased probe audibility + reduction of USoM (red line – nonlinear aided simulation)

➢ Reduction in USoM is not possible with linear amplification because it requires level-dependent gain applied independently in many frequency channels. Multi-channel compression is, to a limited extent, capable of an **apparent** restoration of frequency selectivity in HI listeners.

Conclusions and outlook

- Fast-acting multi-channel compression seems to be more successful than linear amplification in terms of improving psychoacoustic measures of spectral and temporal resolution.
- However, even at very aggressive settings (large number of channels and short time constants), the compressor using NAL-NL1 prescription does not fully restore audibility and the benefit seems to be related to the degree of hearing loss and, hence, residual cochlear compression and frequency selectivity.
- This shows that the amount of audibility information made available by compression is limited.
- Consequences of using the presented system in a speech recognition task are yet to be determined.